BLM3051 - Data Communication
Lecture Notes

Şafak Bilici

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What Is Communication?

- Sharing information - data.
- Telecommunication [1]
- Communication aim: traffic data.
- Telephone, television, etc.
  - Audio, video, image
- Computer
  - Medium (singular)/Media (plural) → 0/1
- Protocol Stack: Software and Hardware

Essentials of Data Communication

- Message
- Sender
- Reciever
- Medium
- Protocol

Data Communication Features

- Delivery
- Accuracy
- Timeliness

Pros Of Computer Network

- Resource Sharing
- Info/Data Sharing
- Load Sharing/Balancing
- Reliability
- Economy
- Efficient communication between in different places.

[1] tele: Greek → far

Evaluation Criteria For Computer Networks

- Performance
    - Transmit time
    - Response time
- QoS
    - Circuit-switched (Synchronous)
        - bit rate, min error rate, transmission rate
    - Packet-Switched (Asynchronous)
        - Max packet size, mean packet transfer rate, mean packet error rate, jitter, mean packet transmit delay
- Reliability / Availability
    - MTBF - Mean Time Between Failure
    - Restoring time
    - 5-9 → 99,999%
- Security
- Scaleable
- Adaptable

Network Standards

- De Jure
    - De jure standards, or standards according to law, are endorsed by a formal standards organization. The organization ratifies each standard through its official procedures and gives the standard its stamp of approval.
    - ISO (International Organization For Standardization
    - ITU, IEEE, ETSI, TIA, ANSI, TSE, IETF
- De Facto
    - De facto standards, or standards in actuality, are adopted widely by an industry and its customers. They are also known as market-driven standards. These standards arise when a critical mass simply likes them well enough to collectively use them. Market-driven standards can become de jure standards if they are approved through a formal standards organization.
    - QWERTY Keyboards, VHS Video Format, PDF document types, buttons on men's shirts are on the right and buttons on women's shirst are on the left, etc.

Computer Network (CN)

- ARPANET (1970s)
- Classification of Computer Networks
    - Technique of Transmission
        - Broadcast (Television)
        - Peer to peer - P2P (machine w machine)

    - Multicast (twitch)
- Network Dimension
    - PAN - Personal Area Network (<10 m)
    - LAN - Local Area Network (< 100 m - 200 m)
    - CAN - Campus Area Network (<1 - 5 km)
    - MAN - Metropolitan Area Network (< 10 - 50 km)
    - RAN - Regional Area Network (< 100 - 200 km)
    - WAN - Wide Area Network (< 1000 km)
- Bit Rate

Topology

Bus Topology

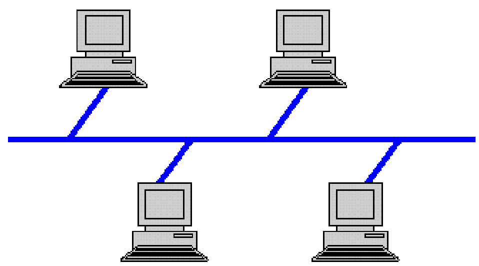

Figure 1: Bus Topology

A bus topology is a topology for a Local Area Network (LAN) in which all the nodes are connected to a single cable. The cable to which the nodes connect is called a "backbone". If the backbone is broken, the entire segment fails. Bus topologies are relatively easy to install and don't require much cabling compared to the alternatives.

It transmits data only in one direction and every device is connected to a single cable. The advantages are: it is cost effective, cable required is least compared to other network topology, used in small networks, easy to expand joining two cables together. The disadvantages are: cables fails then whole network fails, if network traffic is heavy or nodes are more the performance of the network decreases, cable has a limited length, it is slower than the ring topology.

Star Topology

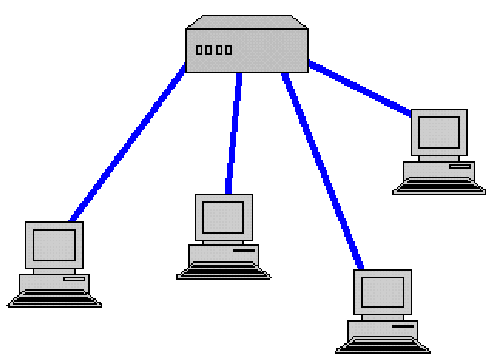

Figure 2: Star Topology

A star topology is a topology for a Local Area Network (LAN) in which all nodes are individually connected to a central connection point, like a hub or a switch. A star takes more cable than e.g. a bus, but the benefit is that if a cable fails, only one node will be brought down. All traffic emanates from the hub of the star. The central site is in control of all the nodes attached to it. The central hub is usually a fast, self contained computer and is responsible for routing all traffic to other nodes. The main advantages of a star network is that one malfunctioning node does not affect the rest of the network. However this type of network can be prone to bottleneck and failure problems at the central site.

Every node has its own dedicated connection to the hub and hub acts as a repeater for data flow. Advantages are: Fast performance with few nodes and low network traffic, hub can be upgraded easily, only that node is affected which has failed, rest of the nodes can work smoothly. Disadvantages are: cost of installation is high, if the hub fails then the whole network is stopped because all the nodes depend on the hub, Pprformance is based on the hub that is it depends on its capacity.

Ring Topology

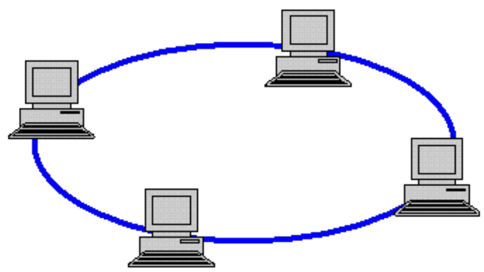

Figure 3: Ring Topology

A ring topology is a topology for a Local Area Network (LAN) in which every device has exactly two neighbours for communication purposes. Typically, all messages travel through a ring in the same direction. A failure in any cable or device breaks the loop and will take down the entire segment. Another disadvantage of the ring is that if any device is added to or removed from the ring, the ring is broken and the segment fails.

A number of repeaters are used for Ring topology with large number of nodes, because if someone wants to send some data to the last node in the ring topology with 100 nodes, then the data will have to pass through 99 nodes to reach the 100th node. Hence to prevent data loss repeaters are used in the network. The transmission is unidirectional, but it can be made bidirectional by having 2 connections between each Network Node, it is called Dual Ring Topology. Advantages are: transmitting network is not affected by high traffic or by adding more nodes, as only the nodes having tokens can transmit data, cheap to install and expand. Disadvantages are: troubleshooting is difficult in ring topology, adding or deleting the computers disturbs the network activity, failure of one computer disturbs the whole network.

Tree Topology

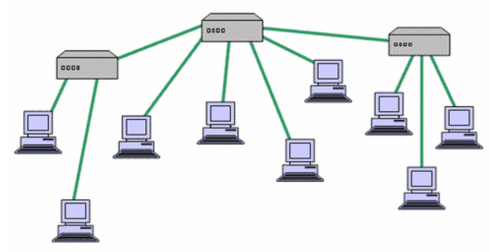

Figure 4: Tree Topology

It has a root node and all other nodes are connected to it forming a hierarchy. It is also called hierarchical topology. It should at least have three levels to the hierarchy. Ideal if workstations are located in groups and Used in Wide Area Network. Advantages are: extension of bus and star topologies, expansion of nodes is possible and easy. Disadvantages: heavily cabled, if more nodes are added maintenance is difficult, central hub fails, network fails.

Mesh Topology

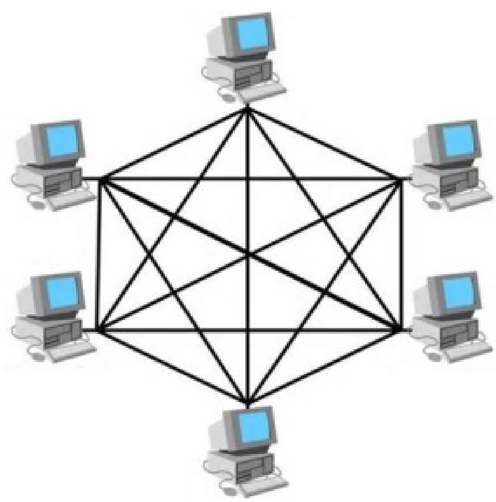

Figure 5: Mesh Topology

It is a point-to-point connection to other nodes or devices. All the network nodes are connected to each other. Mesh topology is fully connected, robust and not flexible. Advantages are: each connection can carry its own data load, provides security and privacy. Disadvantages are: installation and configuration is difficult, cabling cost is more.

Hybrid Topology

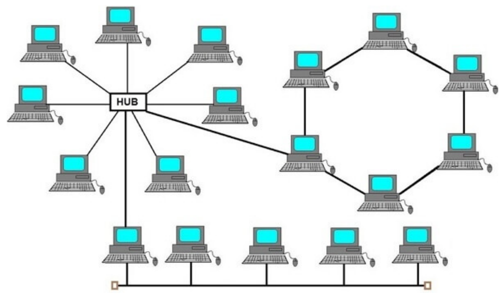

Figure 6: Hybrid Topology

It is two different types of topologies which is a mixture of two or more topologies. For example if in an office in one department ring topology is used and in another star topology is used, connecting these topologies will result in Hybrid Topology (ring topology and star topology). It is a combination of two or topologies and inherits the advantages and disadvantages of the topologies included. Advantages are: reliable as error detecting and trouble shooting is easy. Disadvantages are: complex in design and costly.

Transmission Model

- Simplex: Uni-directional P2P
    - Mouse
    - Barcode reader
- Half-Duplex
    - Radio

Adressing Model

- Broadcast
    - TV
- Multicast
- Anycast
- Unicast

Data Flow Density, Bitrate, Throughput

- Symmetric
- Assymetric

- bps (bit-ps), Bps (byte-ps)

- Throughput

- Response time
- Jitter

WEEK 2

OSI Reference Model

- ISO - 1984
- De Jure
- Features
  - All layers are open
  - Flexible
  - Robust
  - Interoperable
  - Easy to explain
  - 7-layers
  - Never applied / ideal model

Layers In OSI

1. Physical Layer
2. Data Link Layer
3. Network Layer
4. Transport Layer
5. Session Layer
6. Presentation Layer
7. Application Layer

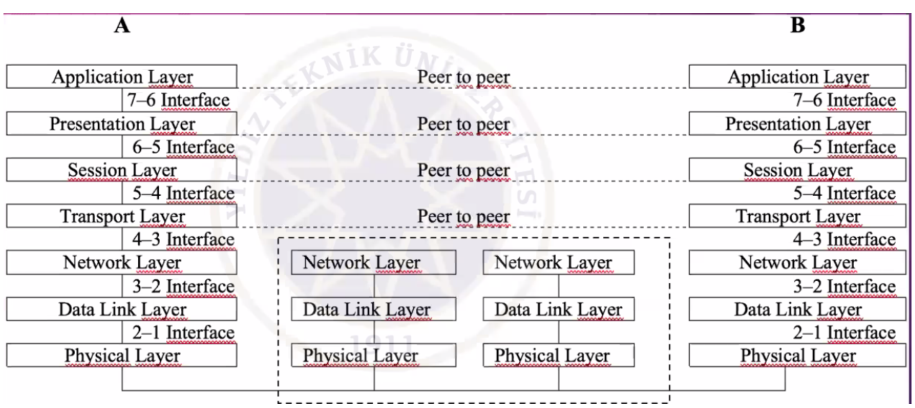

Figure 7: OSI Layers

- Each layers add a header package.
- Only second layer (Data link) add a trailer package.
  - Error Control
- Encapsulation

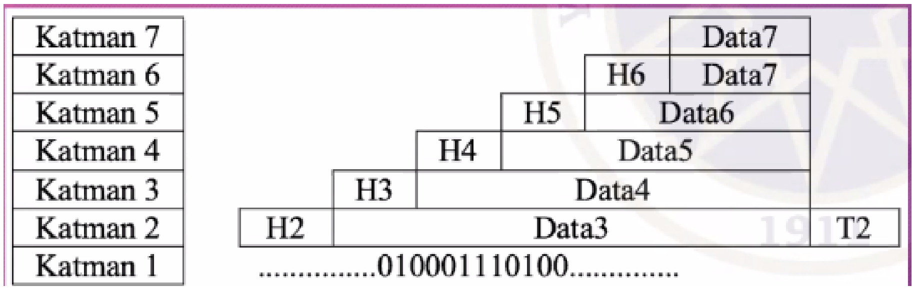

Figure 8: OSI Layers

OSI - Physical Layer

- Cable or noncable
- Responsible for trasmitting bit arrays between peers
- General functions of the Physical Layer:
  - Electromechanic
  - Direction of the package
  - Determining magnitudes of signals
    - Amplitude, Wavelenght, Frequency
  - Initiation and termination of the physical connection.

OSI - Data Link Layer

- Extract/divide frames from the message
- Top layers cannot process big amount of data, so we need to divide frame by frame our data.
- Using acknowledgment (ACK) info;
  - In case of an error
  - In case of not receive the package
  - Re-transmission
- Add header and trailer data to frames.
  - To determine the starting and ending points of the frame
- Header includes:
  - Sender address
  - Receiver adress
  - Order info
- Trailer includes:
  - A code (to check errors)
- To sum up, general functions of the Data Link Layer:
  - Node to node error free delivery
  - Addressing (in header part)
    - MAC Address
  - Access Control

  - Flow Control
  - Error Handling.
  - Synchronization

- In Local Area Network (LAN)
  - DLL divides into 2 different layers
    - LLC (Local Link Control)
    - MAC (Media Access Control)

- Communication at the data link layer is in the same network

OSI - Network Layer

- Network layer şs responsible for
  - Efficient and accurately forwardşng the packet
  - From source to destination over different network links

- Communication at the network layer is in the different network.
  - Router (3rd level devices)

- Switching
  - Connection oriented
    - like telephone infrastructure system

- Routing
  - Determining the path between sender and receiver
  - Connectionless
    - Delivering packages
  - In DLL, data transfer occurs between nodes

- Address must be different from DLL's addresses.
  - Logical addresses

- Data transfer occurs between the source and the destination.
- To sum up, general functions of the network layer:
  - Source to Destination packet delivery
  - Logical addressing
  - Routing
  - Address transformation
    - Between logical and physical addresses
  - Multiplexing
    - Multiple physical connections on a single network connection at the same time.

OSI - Transport Layer

- Responsible for the transmission of data
    - from source to destination
- Network layer responsible for delivering data
- Transport layer responsible for delivering packages
    - data = package [ ]
- Data transmission is between applications, not computers.
- An additional addressing mechanism is required
    - to distinguish the applications form each other
    - Service Access Point - SAP
        - Ports
        - Sockets
- Transport layer divides incoming information into pieces (segment) in sizes supported by the infrastructure
    - Segmentation
        - Sequence number
        - Re-assembly
- There are two types of services
    - Connectionless
        - like post services
    - Connection oriented
        - Like phone services
            - Establish connection
            - Data transmission
            - terminate connection
        - More control over the data to be transferred
- To sum up, general functions of the Transport Layer:
    - Data transmission between source and destination nodes
    - to provide data flow between applications with the help of service points
    - segmentation and re-assembling
    - ensuring connection control
        - connectionless — connection oriented

OSI - Session Layer

- This layer is responsible for ensuring continuity.
    - Synchronization
- Decision mechanism
- Choosing connection type
    - Half-duplex
    - duplex

- Session data transfering
  - Password
  - Logon verification
- Sessions can be split into sub-sessions to ensure the reliability of the connection
- To sum up, general functions of the Session Layer:
  - Managing the session
  - Communication control
    - if it is half-duplex
  - Ensuring synchronization
  - Gracefull close

OSI - Presentation Layer

- General functions of the Presentation Layer:
  - Provides interoperability by eliminating possible differences in information representation between devices dyuring data communication
    - Abstract data syntax
  - Encryption and Decryption
  - Compression and Decompression
- User interfaces
  - Electronical mail
  - File transfering
  - Remote desktop
  - Internet explorer
  - etc.

WEEK 3

Signals

There are two types of signals. Analog (continious) and digital (discrite). Both analog or digital, signals can be classified as periodic or non-periodic.

Analog Signals

A simple analog signal defined as

$$f(t) = A\sin(2\pi ft + \theta)$$

and complex analogue signal is defined as

$$f(t) = \sum_{n=1,3,5}^{\infty} \frac{1}{n}\sin(2\pi nft)$$

- v - Amplitude
    - Volt -v
    - Amper - A
    - Watt - W
- f -Frequency
    - Cycle
    - Hertz - hz
- phase
    - degree
    - radian - π

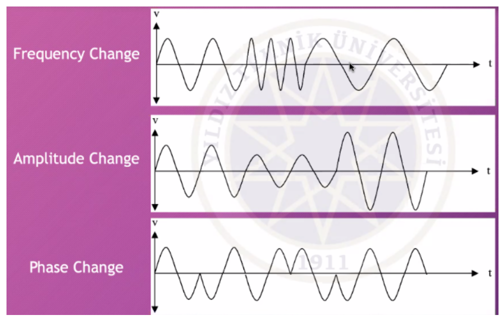

Figure 9

Digital Signals

- Non-periodic
- Bit-rate
    - the number of bits transferred in one second.
- Bit-interval
    - the time it takes to transmit one bit (in seconds)

Elements That Negatively Affect Communication

- Distortion
    - Attenuation
        - dB
        - Solutiın: Amplifying
            - Analog?
            - when analog signal is amplified, also the noise is amplified.
    - Noise
        - Even idle mode
        - Thermal noise
            - motion of atomic fragments
        - Impulse noise
            - Random electromagnetic signal
    - Cross talk
    - Delay
    - Propogation: Velocity of a sinusodial signal in a transmission line.

Data Carrying Capacity

-
  - The amount of data can be sent per unit time
  - H: Band width
  - V: Number of discrete voltages
  - $data_{vel} = 2H \log_2 V \ bit/sec$
  - Not consider the noise
- Noise (dB)
  - Signal Strength (sent): S
  - Stength of the current noise: N
  - $SNR = 10 \log_{10} \frac{S}{N} \ dB$
- Shannon-Hartley
  - Data velocity with noise
  - $data_{vel} = H \log_2 2(1 + \frac{S}{N}) \ bit/sec$
- First, the highest data rate to be achived is found according to the shannon-hartley formula.
-

Example: Since it is known that SNR vale on a transmission channel between 3KHz - 4KHz is 24dB, what is the maximum rate that can be obtained and the number of discrete levels that can be used for transmission?

$$SNR = 10 \log_{10} \frac{S}{N} \ dB$$
$$= 24 \ dB$$
$$\log_{10} \frac{S}{N} = 2.4$$
$$\frac{S}{N}$$
$$= 10^{2.4}$$
$$data_{vel} = H \log_2 (1 + \frac{S}{N}) \ bit/sec \rightarrow H.log_2 10^{2.4} \approx H \times 8$$
$$data_{vel} = 8H \ bps$$
$$data_{vel} = 2H \ \log_2 V$$
$$= 8H$$
$$\log_2 V = 4$$
$$V = 16$$

Coding of Signals

- Digital - Digital
  - computer - printer
- Analog - Digital
  - Microphone - Computer
- DİGital - Analog
  - Computer - Communication Lines
- Analog - Analog
  - Radio - Radio Signal Lines

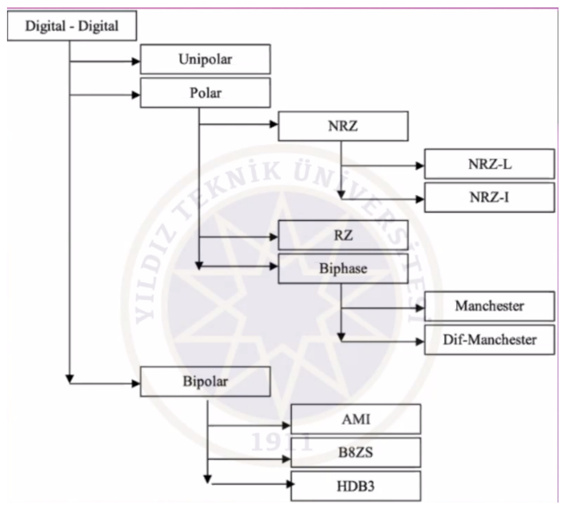

Figure 10

Digital2Digital - Polar Coding

- 3 main types
  - Non Return to Zero (NRZ)
    - Non Return to Zero-Level (NRZ-L)
    - Non Return to Zero-Inverted (NRZ-I)
  - Return to Zero (RZ)
  - Biphase
    - Best Digital2Digital Technique
    - Manchester
    - Differential Manchester

Digital2Digital - Bipolar Coding

- 3 Voltage levels
  - (+,- and 0) like RZ
  - 0V $\rightarrow$ 0
  - +,- $\rightarrow$

◦ AMI (Alternate Mark Inversion)
◦ B8ZS (Bipolar 8 zero Synchronizing)
◦ HDB3 (High Density Bipolar 3)

Analog2Digital

- PAM (Pulse Amplitude Modulation)
- PCM (Pulse Code Modulation)
- Nyquist Theorem
    - Sampling at least twice the highest frequency component is required

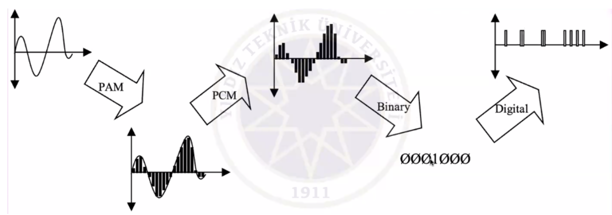

Figure 11

Digital2Analog

- ASK (Amplitude Shift Keying)
- FSK (Frequenct Sgift Keying)
- PSK (Phase Shift Keying)
    - It is not affected by voltage additions caused by external enviroment effects such as ASK, and bandwith related problems such as FSK.
- QAM

Analog2Analog

- AM (Amplitude Modulaton)
- FM (Frequency Modulation)
- PM (Phase Modulation)

Digital Data Transmission Techniques

- Medium spec;
  - Connector type to provide mechanical connection in the transmission medium
  - Number of wires
    * Signal type
    * Purpose
  - Frequency, amplitude and phase

Parallel Transmission

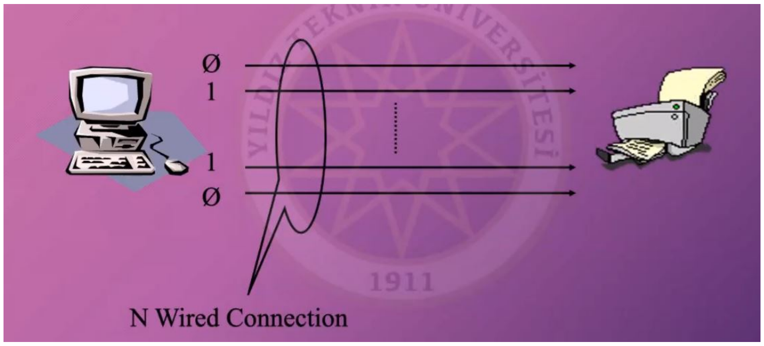

Figure 1: Parallel Transmission

Serial Transmission

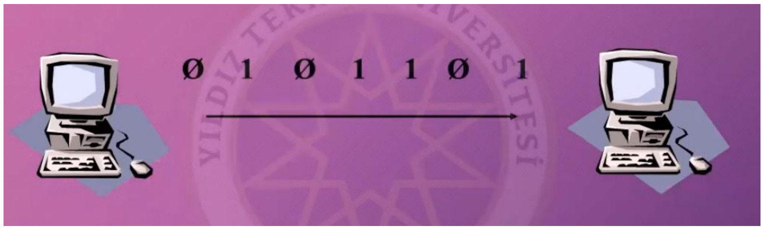

Figure 2: Serial Transmission

- RS-232-C
  - 9 wires
    * RX
    * TX
    * GND
    * 6x Flow Control Wire
  - 155 kbits/sec
  - 15 meters
  - NRZ-L
    * $(-15, -5)V_{DC} \rightarrow 1$
  - RS-422: 300meters
- Asynchronous transmission in WAN
  - 2 wires
- Synchronous tranmission in WAN
  - 4 wires

Asynchronous Serial Transmission

- Simple, Cheap
- The data arrival rhythm between the sides in not the same.
- It is not possible to tell when the incoming transmission started and when it ends
- Receiver and transmitter must agree on how long each bit will remain on the line.
- Start bit:0, positive voltage
  - 8-N-1
    - 1 + 8 + 1 -> LSB
    - N: not parity bit
  - 7-E-1
    - 1 + 7 + 1 (Even)
  - Stop bit: 2-bits long
- Since the communication between the sender and receiver is not made simultaneously, there are **gaps** of variable duration between the bytes sent.

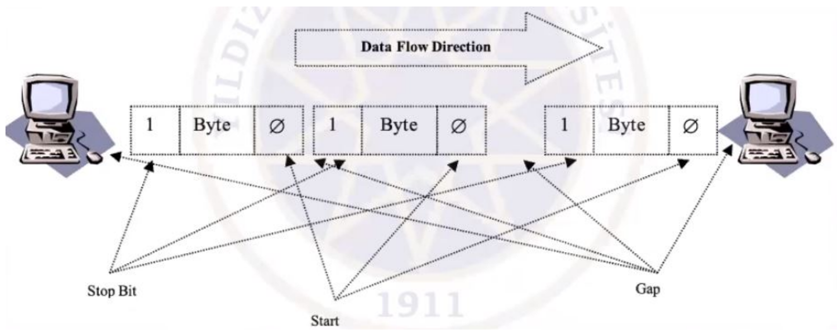

Figure 3: Data Transmission in Async. Serial Transmission

- Time Skew
  - If the processing speed difference between the two sides is 5%
- Dial-up
  - Carrier Signal

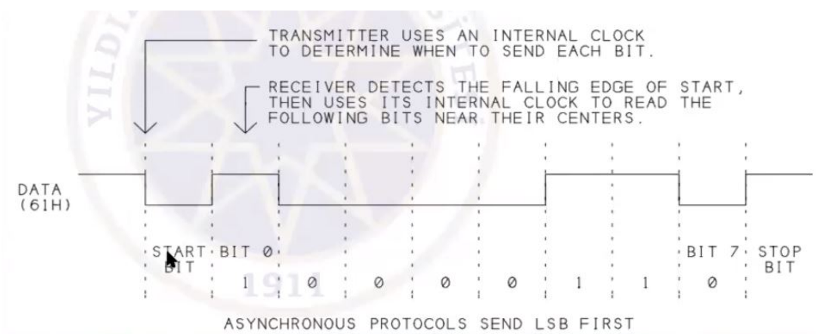

Figure 4: Bit Transmission

Synchronous Serial Transmission

- Much more big data compare to Async within one transmission(>1000 byte)
- If there is no data transmission
  - A special bit sequence is sent in the line

- In order for the information to be transferred properly, **operations must be carried out depending on a common timing mark**.
- Like an assembly line
- Clock line: A different line
  - Clock pulse
  - Short distance transmissions
- Logical Level Synchronization
  - Preamble Bit Array
  - Postamble Bit Array
  - Max 100 bits for control data.
  - HDLC (High Level Data Link Control)
    - 48 bits for control purposes.
    - Example
      - If we want to transfer 1000 character in HDLC mode, how much bits send?
      - 1 character → 8 bit
      - 1000 character → 1 block
      - Control data → 48-bit
      - 1 block → 8000 bit
      - 8000 + 48 → 8048 bit
      - Load of control data per block → 48 / 8048 ≈ 0.6%

Synchronous ST	Asynchronous ST
+ Much more efficient usage + Better error control + High transmission speed	+ Simple + Cheap + Additional effort required for timing + Limited speed - Limited error control mechanism (parity) - 20% loss due to start / end bits

DTE-DCE Interfaces

- DCE (Data Circuit-Terminating Equipment)
  - Modem
- DTE (Data Terminal Equipment)
  - Computer
  - Printer
  - Fax
  - etc.

Figure 5: DTE-DCE Interface

Transmission Medium

- Wire
- Light
- Radio Wave

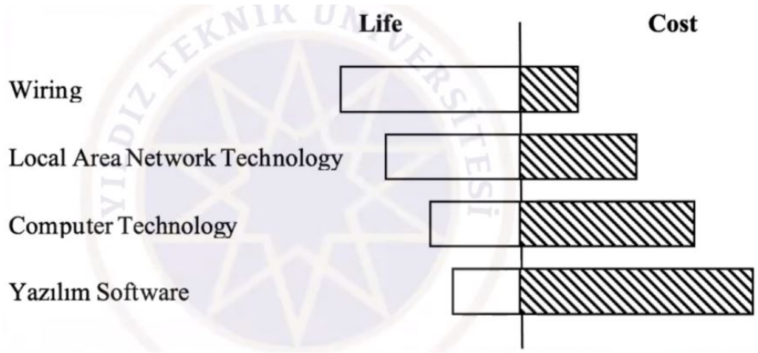

Figure 6: Life and Cost

Guided Media

- Coaxial Cable
  - AUI (Attachment Unit Interface)
  - Ethernet
  - Thick: 10mm

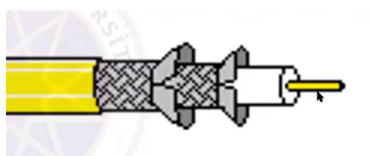

Figure 7: Coaxial Cable Structure

- Twisted Pair

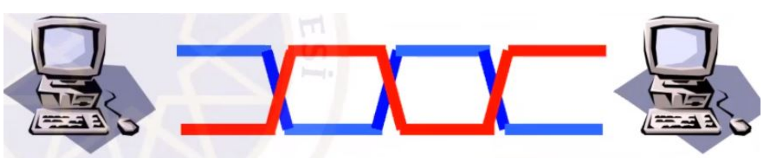

Figure 8: Twisted pair Cable Structure

  - DGM (Data Grade Medium)
  - CATs
  - 2-12 twist/step
  - Different Colors
  - There are 3 different types:
    * UTP (Unshielded Twisted Pair)
      · 100m = 90m + 10m
    * ScTP/FTP (Screened Twisted Pair/Foiled Twisted Pair)
    * STP (Shielded Twisted Pair)

Figure 9: UTP

Figure 10: ScTP/FTP

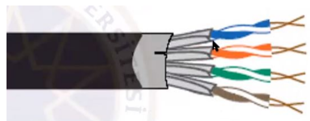

Figure 11: STP

- UTP cables category criterias:
  - Signal Frequency
  - Wire length
  - Correct connections
  - Attenuation
  - NEXT (Near-End Crosstalk)
  - PSNEXT (Power Sum NEXT)
  - FEXT (Far-End Crosstalk)
  - ELFEXT (Equal Level FEXT)
  - PSELFEXT (Power Sum ELFEXT)
- CAT 5e
  - gigabit Ethernet
  - 4 pieces of 2
  - Propagation delay
    - Skew
      - Fastest - Slowest
- Classification of UTP Cables

Type	Usage Purpose	Freq. (MHz)	Connector Type	Usage Area
Cat-1	Voice	1	6P2C/RJ-11	Voice/Phone
Cat-2	Voice - Data	4	8P8C/RJ-45	Voice 4Mbps TokenRing / Terminal
Cat-3	Voice - Data	16	8P8C/RJ-45	Voice / 10Base-T / 25Mbps ATM
Cat-4	Data	20	8P8C/RJ-45	10Base-T / TokenRing
Cat-5	Data	100	8P8C/RJ-45	100Base-T / 100Base-T / ATM / CDDI
Cat-5e	Data	>100	8P8C/RJ-45	100Base-T / 1000Base-T
Cat-6	Data	250	8P8C/RJ-45	1000Base-T / 10GBase-T@55m
Cat-6a	Data	>500	8P8C/RJ-45	10GBase-T
Cat-7	Data	600	8P8C/RJ-45	10GBase-T
Cat-7a	Data	1000	8P8C/RJ-45	40Gbps@50m / 100Gbps@15m
Cat-8	Data	>1.200	8P8C/RJ-45	>40 Gbps@30-50m

Fiber Optic Cables

- 300.00 km/sec
- >= 100 Gpbs (reached 500 Gpbs)
- Core
- Cladding
- Primary buffer
- Secondary buffer

- Armor
- Plastic Shield
- There are two types of fiber:
  - SMF (Single Mode Fiber)
  - MMF (Multi Mode Fiber)

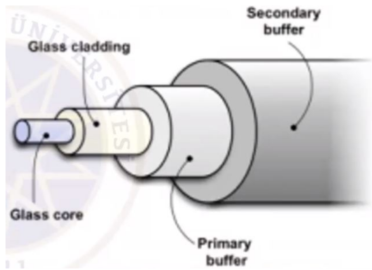

Figure 12: Fiber Optic Cable Structure

- Single Mode Fiber (SMF)
  - Core = 9μm
  - Light wavelength: 1.3 - 1.5 μm
  - 1.3μm $\approx$ 9μm $\rightarrow$ Transmission carried out as a single, unbreakable beam

- Advantages of Fiber Optic Cables over Copper Cables
  - Broad Bandwidth
  - Immunity to Electromagnetic Interference
  - Attenuation
  - Insulation
  - Space Saving
  - Security
    * Eavesdrop

Unguided Media

- Technologies that aim to use the atmosphere
  - RF (Radio Frequency)
  - Microwaves
  - IR (Infra Red)
- Ionosphere
  - Ground propagation < 2 MHz
  - Sky propagation 2-30 MHz
  - Line of sight propagation > 30 MHz

Radio Frequency

- 3 kHz - 1 GHz
- Television and Radio
- Omnidirectinal
- Antennas do not need to be aligned
- RF can go through the wall
- Obtain approval from authorities to use RF

Microwaves

- Stellite - Ground Station
- Parabolik and horn antennas
  - Unidirectional
  - LOS - Line Of Sight
- Microwaves can not go through the wall
- It can be harmful to the living creature between the transceiver, depending on the signal strength used

Infra Red

- 300GHz - 400THz
- Point-to-point
  - Device's remotes
- Infra Red can not go through the wall
- Tapping-eavesdropping
- Jamming Immune
- 75 kbps in max. 8m distance

Multiplexing

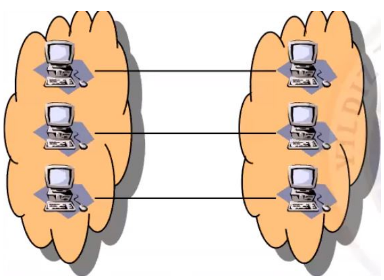

Figure 13: Transmission Without Multiplexing

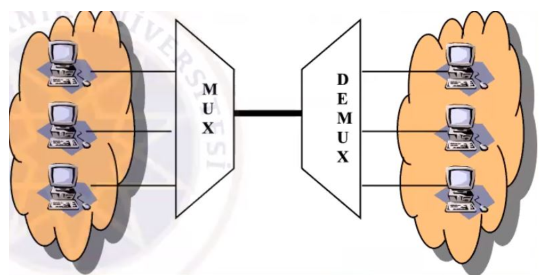

Figure 14: Transmission With Multiplexing

Multiplexing Technics

- FDM (Frequency Division Multiplexing)
- WDM (Wavelength Division Multiplexing)
- TDM (Time Division Multiplexing)

Frequency Diviion Multiplexing (FDM)

- $\Sigma(p2pBW) < totalBW$
- Each signal has a different carriage signal
  - The signal to be sent is the sum of the carrier signals
  - Voice: 300-3300HZ BW
  - Guarded Band
- Television and radio broadcasts

Wavelength Division Multiplexing (WDM)

- Like FDM in FO

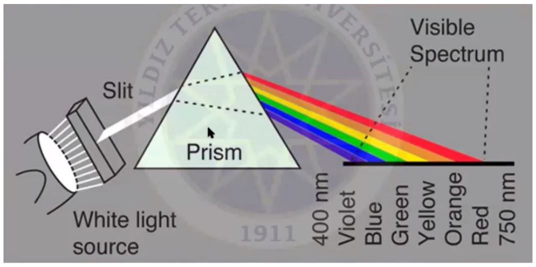

Figure 15: Spectrum

Time Division Multiplexing (TDM)

- max(p2p BW) < BW

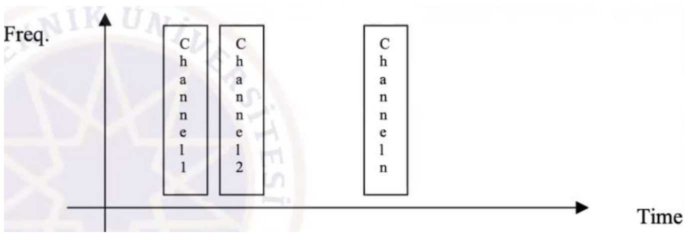

Figure 16: Caption

- 2 Types
  - Synchronous TDM
    - Data
    - Digitized Voice
  - Asynchronous TDM

Synchronous TDM

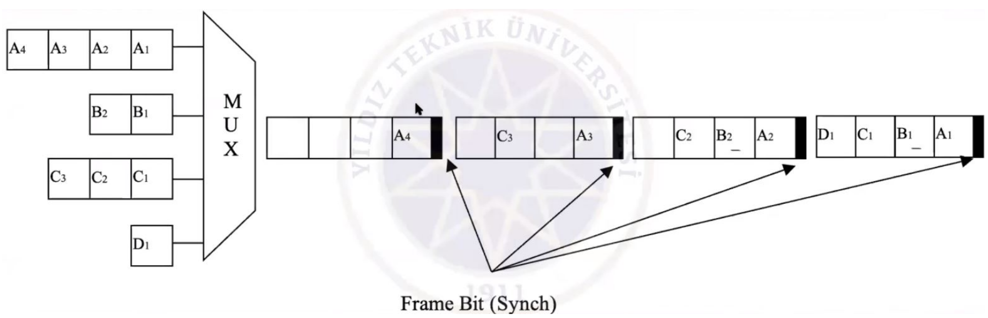

Figure 17: Synchronous TDM Visualization

Asynchronous TDM

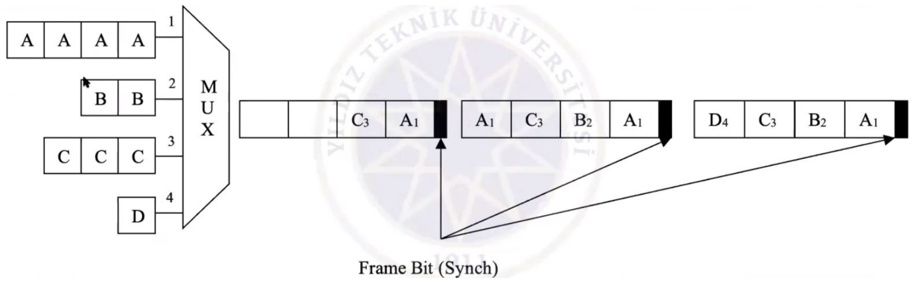

Figure 18: Asynchronous TDM Visualization

Error Detection and Correction Techniques

- Data Link Layer (in OSI model)
- Error reasons
  - Attenuation
  - Delay Distortion
    - Video + Voice
    - Problem in time sensitive conditions
  - Noise in the communication environment
    - Thermal noise
      - Random electron motion
    - Intermodulation noise
    - CrossTalk
    - Impulse Noise

Error Types

- Single bit error
- Multi bit error
- Error bursts

Error Detection

- Both sides have original data?
- Sending data twice?
- Control block?
  - 4 different types
    - VRC (Vertical Redundency Code)
    - LRC (Longitudial Redundency Code)
    - CRC (Cyclic Redundency Check)
    - Checksum

Vertical Redundancy Code (VRC)

- Parity check
- Simple error coding technique
- The number of errors should be **odd**.
- XOR operation

VRC	Data						
1	0	1	0	0	1	1	0

Table 1: Data Sent

VRC	Data						
1	0	1	0	0	1	1	0

Table 2: Data Received 1

VRC	Data						
1	0	1	1	0	1	1	0

Table 3: Data Received 2

VRC	Data						
1	0	1	1	0	1	0	0

Table 4: Data Received 3

Longitudial Redundency Code (LRC)

- LRC is 2D - VRC

	Byte 1		Byte 2		Byte 3		Byte 4		LRC
	1		0		1		1		1
	0		0		1		1		0
	0		1		0		1		0
	1		1		0		1		1
	1		0		1		0		0
	0		1		1		0		0
	1		0		0		0		1
VRC	0		1		0		0		1

Table 5: LRC Example

Cyclic Redundency Check (CRC)

- The data to be sent is divided into a predetermined prime polynomial.
- The remainder value is added to the data to be sent as an error control code.
- Example: Data Sent: 100100, polynom: $x^3 + x^2 + 1$, CRC = ?

Checksum

- The sender divides the data into N-bits parts (usually 16 bits are used).
- The parts are collected using the first complementary arithmetic.
  - In this way, a total value of only N bits is obtained.
- Calculate two's complement using summed value

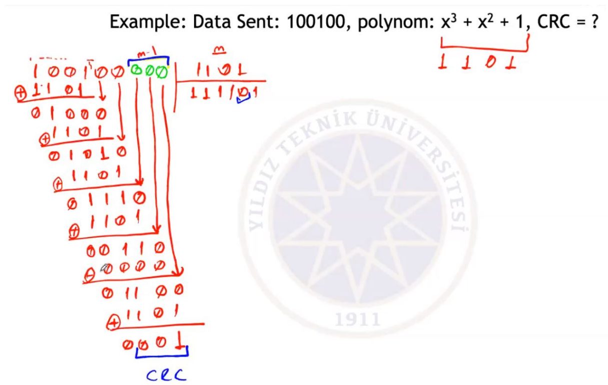

Figure 19: Solution

- The calculated value is added to the end of the information to be sent.

- The checksum detects all of the odd errors and most of the even numbers.
  - However, if one or more bits in a part are 0 when are 1, but there is a 0 when 1 in another part, the error will not be understood because there will be no difference in this column sum.

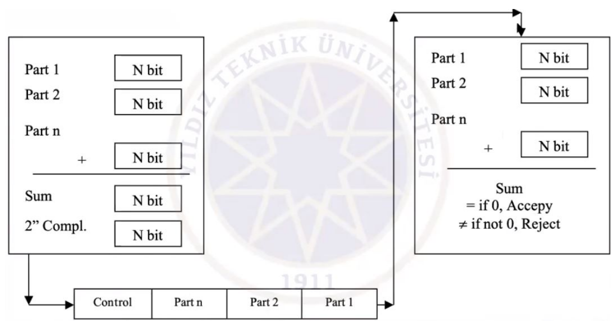

Figure 20: Checksum Structure

Error Correction

- 2 methods
  - Send data again
  - If one bit error
    - Hamming Code / Distance

Hamming Code

- If we sent m bit data, the error occurs in 1,2,...,m bit
- Adding error-free state, the data length will be **m+1**
- Control block length must be $\log_2(m+1) \leq r$
- **m + r** bit must be sent error-free
- So, control block length must be $\log_2(m+r+1) \leq r$
- (1, 2, 4, 8, 16. bits)

B_{11}	B_{10}	B_9	B_8	B_7	B_6	B_5	B_4	B_3	B_2	B_1
D_7	D_6	D_5	R_4	D_4	D_3	D_2	R_3	D_1	R_2	B_1

	R_4	R_3	R_2	R_1	Info
0	0	0	0	0	Error-free
1	0	0	0	1	Error-free
2	0	0	1	0	Error-free
3	0	0	1	1	Error-free
4	0	1	0	0	Error-free
5	0	1	0	1	Error-free
6	0	1	1	0	Error-free
7	0	1	1	1	Error-free
8	1	0	0	0	Error-free
9	1	0	0	1	Error-free
10	1	0	1	0	Error-free
11	1	0	1	1	Error-free

- $R_1 = B_1 \bigoplus B_3 \bigoplus B_5 \bigoplus B_7 \bigoplus B_9 \bigoplus B_{11}$
- $R_2 = B_2 \bigoplus B_3 \bigoplus B_6 \bigoplus B_7 \bigoplus B_1 0 \bigoplus B_{11}$
- $R_3 = B_4 \bigoplus B_5 \bigoplus B_6 \bigoplus B_7$
- $R_4 = B_8 \bigoplus B_9 \bigoplus B_1 0 \bigoplus B_{11}$

Data Link Control

- Basic taks of the data link layeR:
  - Framming and determining start and end points to ensure synchronization
  - Flow control
  - Error control / Retransmission
  - Adressing
  - Line dicipline / Link management

Line Dicipline / Link Management

- Enq/Ack (Enquiry / Acknowledgement)
- Poll/Select Connection Management

Enq/Ack (Enquiry / Acknowledgement

- Point to point (in WANs)
- Units are expected to have equal properties

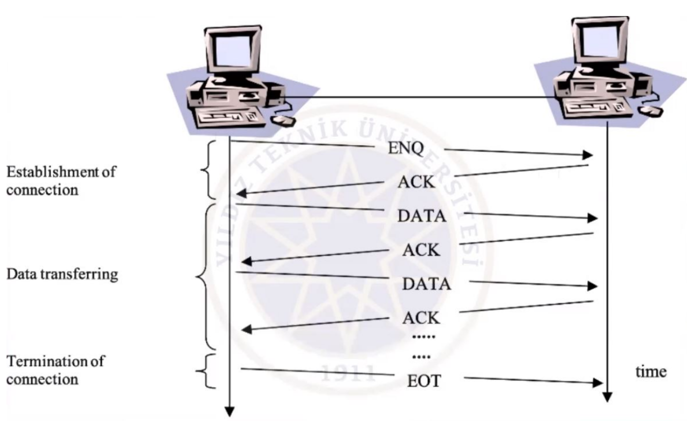

Figure 21: Enq/Ack Demonstration (Best Case)

Poll/Select Connection Management

- Multi-point (in LANs)

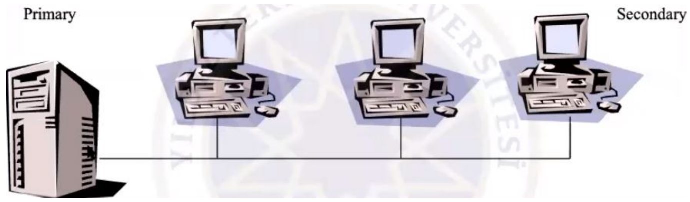

Figure 22: Poll/Select Demonstration

Flow Control

- Overwhelm
- Buffer
- There are two basic techniques:
  - Stop & Wait
  - Sliding Window

Stop & Wait

- ACK is required for every transfer.
- Pros:
  - Packages consist of smaller pieces
  - Effective use of buffer
  - Medium is busy for a shorter time
  - Error probability decreases
  - Error control processing times are shortened.
  - Wait time may be shorter for other devices in LANs.
- Line Utilization (U) Rate
  - t_{frame}: Transmission time of a single frame
  - t_{prop}: The time it takes from the sender to the receiver
  - t_{ack}: The time it takes for all bits of the ACK to exit the receiver
  - $T_F : t_{frame} + t_{prop} + t_{ack} + t_{prop}$
  - $T_F : t_{frame} + 2t_{prop}$ (t_{ack} is too small so it is being ignored)
  - $U = \frac{t_{frame}}{t_{frame}+2t_{prop}}$
  - **Example:**
    * Data communication is made between two points at a distance of 1000km (d = 1000km = $10^6 m$) at a speed of 155.52 Mbps (R=155.52 10^6 bit/sec)
    * The transmission speed of the line is 200.000.000 m/sec (V=2 10^8 m/sec).
    * Frame size is 424 bits (L = 424 bit).
    * What is the Line Utilization (U) in Stop & Wait Flow Control mode?
  - **Answer**
    * a = $\frac{t_{prop}}{t_{frame}} \rightarrow U = \frac{1}{1+2a}$
    * $t_{prop} = \frac{distance}{velocity} = \frac{d}{v}$ and $t_{frame} = \frac{frameSize}{dataRate} = \frac{L}{R}$

Sliding Window

- U rate is low in Stop & Wait
- The sender sends a certain amount of data to receiver without ACK data.
- Frames are transmitted in convoys.
- The receiver can send ACK data for several frames.
- Frame number is necessary
  - n-bit $\rightarrow 2^n$ frame
- Piggy backing : Mesaj yollarken sonuna ACK verisini eklemek

Sliding Window - Sender Side

- Window size: $2^n - 1$
  - Example: If frame sequence number bit length is n=3, windows size is $2^n - 1$ = 7

Figure 23: Pointer Before Sending

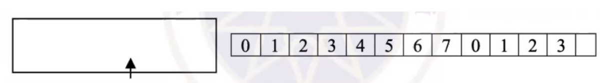

Figure 24: Pointer After Sending

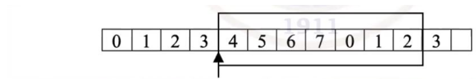

Figure 25: Buffer After Sending

Sliding Window - Receiver Side

Figure 26: Pointer Before Receiving

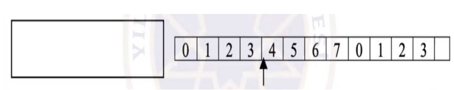

Figure 27: Pointer After Receiving

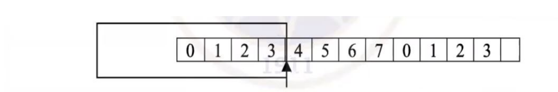

Figure 28: Buffer After Receiving

Sliding Window - Line Utilization (U) Rate

- In Stop & Wait a = $\frac{t_{prop}}{t_{frame}}$
- In Sliding Windows t_{frame} = 1 $\rightarrow a = t_{prop}$
- If w (window size) $\geq$ (2a + 1)
  - U = %100
- If w < (2a + 1)
  - U = $\frac{w}{2a+1}$
- $U = \begin{cases} 1 & w \geq 2a+1 \\ \frac{w}{2a+1} & w < 2a+1 \end{cases}$

Error Control, Automatic Repeat reQuest (ARQ)

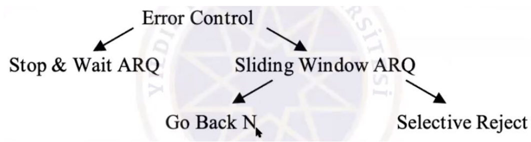

Figure 29: Error Control

Stop & Wait ARQ

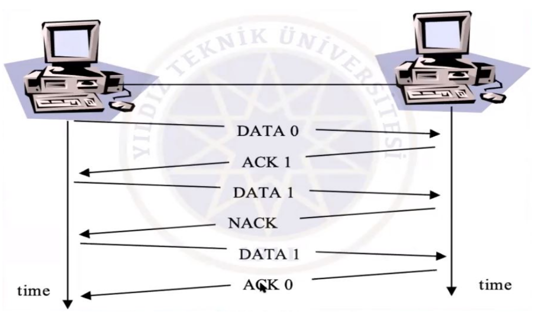

Figure 30: Data reached with error(s)

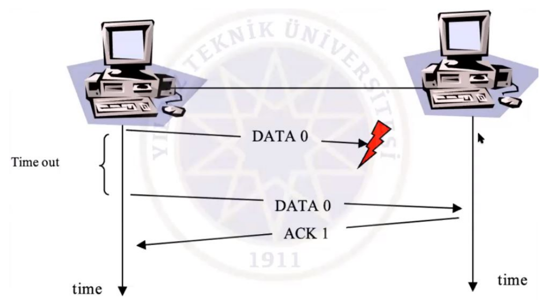

Figure 31: Data could not reached

Sliding Window ARQ

- **There are som differences** caused by the sliding window technique when the frames inside the window are sent **without a receipt**.
  - The sender continues to **store the frames in the buffer until** it receives **ACK** for the frames.
  - In the **ACK / NACK information** coming from the **receiver**, there will be **a number field** showing **which** numbered frame **it is for**.
  - Receive Ready
    * RR 3 and RR 6 means: I have **received 3, 4, 5** numbered frames, **waiting for frame 6**.
  - **Each faulty frame is immediately reported by the receiver** to the sender.
    * REJ - Reject
    * SREJ - Selective Reject
  - **The sender also has a timer** in the sliding window approach.
    * Lost data frame
    * Lost acknowledge frame

Sliding Window - Go Back n ARQ

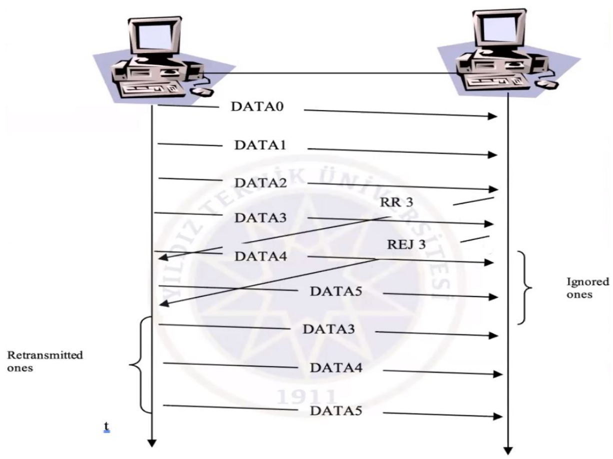

Figure 32: Data reached with error(s)

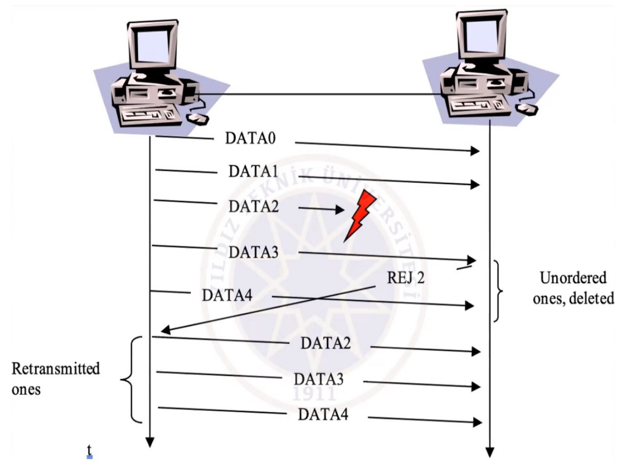

Figure 33: Data could not reached

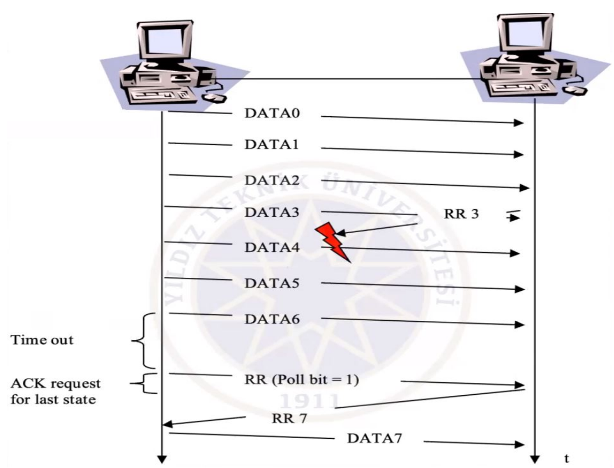

Figure 34: RR could not reached

Sliding Window - Selective Reject / Selective Repeat ARQ

- In this technique, the receiver will receive the frames unordered.
  - Search and Sort Algorithms are necessary.
  - Processing complexity increases
    - ∗ In Go Back n: w = $(2^n - 1)$
    - ∗ In Selective Reject: w $\leq (2^n + 1)/2$
    - ∗ w : window size
  - SREJ
  - The receiver accepts frames without error after faulty frame.
  - Frames will come in different order due to faulty frames.
    - ∗ Duplicated ones

Data Link Protocols

- Protocol is a set of rules used to perform the necessary operations during data flow.
  - Synchronous
  - Asynchronous

Data Link Controls (DTC)

- Components
  - Software
  - Hardware (UART/USART)
- Tasks
  - Synchronous Transmission
    * Physical Level: Common timing signal
    * Logical Level: Special bit or bit-arrays
  - Flow Control
  - Transmission Rules
    * Which one is sender/receiver?
    * Whether frames are for data or control purposes

Asynchronous Protocols

- Used for connections made with a **modem**
- Logical Sync.
  - Start bit
  - End bit
- There may be gaps of variable sizes between data blocks.
- Cons: Additional data
- Cons: Slow transmission
- Most Common Examples:
  - X-Modem
  - Y-Modem
  - Z-Modem
  - Kermit

Synchronous Protocols

- Instead of start and end bits, FLAGS is used
  - Synchronization premise (SYN) bit-arrays
  - Synchronization successor (EOT) bit-arrays
- 2 types:
  - Physical Level Synchronization
    * Common Clock Signal
  - Logical Level Synchronization (in Data Link Layer)
    * FLAGs
- Thanks to the fast transmission
  - Used in LAN, MAN and WAN technologies
- The protocol perceives the data sent as a consecutive byte sequence.
  - According to the coding system used (ASCII or EBCDIC)

Synchronous Protocols - Byte Oriented

- *Character Oriented
- ASCII or EBCDIC coding

Control Chars	Explanation
SYN	Synchronous idle (makes the channel active)
PAD	Frame PAD (used for completion)
DLE	Data Link Escape (Escape char for control chars)
ENQ	Enquiry (Request)
SOH	Start of Heading
STX	Start of Text
ITB	End of Intermediate Block
ETB	End of Transmission Block
ETX	End of Text
EOT	End of Transmission
BCC	Block Check Count (LRC->1 byte, CRC->2 bytes)
ACK0	Acknowledge Even Numbered Block
ACK1	Acknowledge Odd Numbered Block
WACK	Wait Before Transmitting
TTD	Temporary Text Delay (While filling buffer in sender side)
RVI	Reverse Interrupt (Request for urgent response)
NUL	(Filling spaces)

- 2 types of frames
  - Control frames
  - Data frames

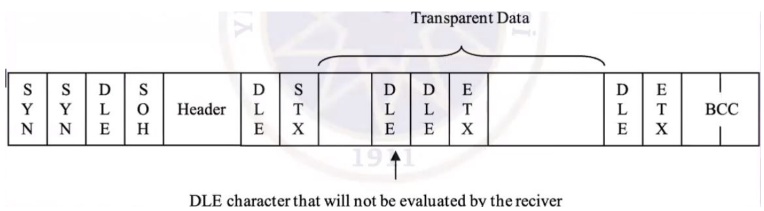

Figure 35: Example

  - Datanın başına ve sonuna STX(Start of Text) ve ETX(End of Text) komutları eklenirken datanın içinde de STX ve ETX karakterleri geçebileceği için başların DLE (Escape character) ekleniyor. Fakat gelen verinin içinde de şansa DLE ve ETX gibi bir şey peş peşe geliyo olabilir bu durumda da 1 tane daha DLE ekliyoruz.

Synchronous Protocols - Byte Oriented - BSC(*Binary Synchronous Communication*)

- IBM
- Used until the late 1960s
- General Specs:
  - Suitable for **point-to-point** or **multi-point** connections
  - Half duplex
  - Use Stop & Wait for Flow Control and ARQ
  - Code dependent

Synchronous Protocols - Bit Oriented

- Used more actively than byte oriented protocols
  - Fit more information into a shorter frame size
  - Less faced with data transparency problem
- All bit oriented protocols reference HDLC (High Level Data Link Control)
  - ISO
- General Specs:
  - Suitable for point-to-point or multi-point connection.
  - Support Half Duplex and Duplex
  - Use Sliding Windows for Flow Control and ARQ
  - Code independent

HDLC (High Level Data Link Control)

- Concepts used in HDLC
  - Station types
    - Primary
    - Secondary
    - Combined
  - Configuration
    - Unbalanced
    - Balanced (not defined in HDLC)
  - Models of communication
    - NRM (Normal Response Mode): Unbalanced. The usual primary/secondary relationship.
    - ARM (Async. Response Mode): Unbalanced. Secondary station transmit data without primary station's permission if line is available.
    - ABM (Async. Balanced Mode): Balanced

Modes of Communication	NRM	ARM	ABM
Station Types	Primary/Secondary	Primary/Secondary	Combined
Transmission Starter	Primary	Primary/Secondary	Any of them

HDLC Frame Structure

I-Frame	Information	It is used to carry user data and related control information.
S-Frame	Supervisory	It is the type of frame used at the data link layer to perform functions as error and flow control.
U-Frame	Unnumbered	It is a special purpose management frame used to provide system management.

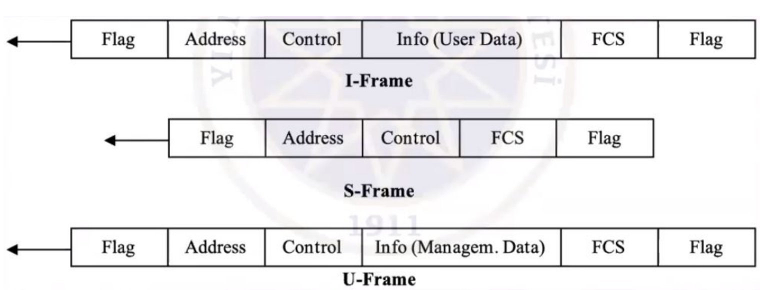

Figure 36: Demonstration of Frames

HDLC Frame Structure - FLAG Field

- Consist of 8-bits
  - 01111110
- Determining start and end point of frames
- Ensure synchronicity
- Critical point for data transparency
  - Bit stuffing
    - Sender add a 0-bit between 1's (like escape char)

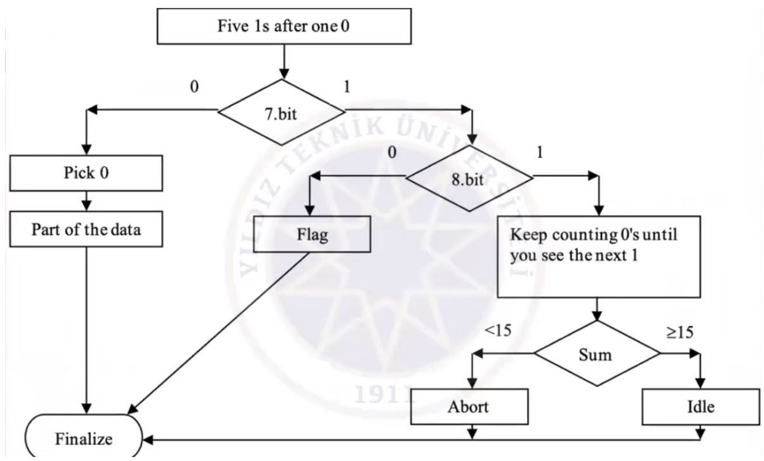

Figure 37: Flowchart of Bit stuffing

HDLC Frame Structure - ADDRESS Field

- Contains the address of the secondaries.
- Address data is in Network Layer (Third Layer)
  - Used to determine whether;
    - Is it command? or is it answer?

7 bit adres alanı	1

Table 6: Single byte adressing

7 bit adres alanı	0	7 bit adres alanı	1

Table 7: Multi byte adressing

HDLC Frame Structure - CONTROL Field

- 1 or 2 byte length
  - If w=7 in sliding window technique, length is 1
  - If w=127 in sliding window technique, length is 2
    - In application with high line delays suc as WAN

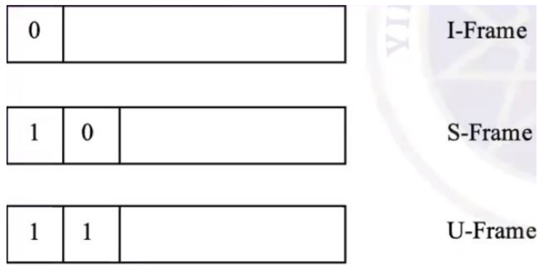

Figure 38: Frames' starting bits

HDLC Frame Structure - I-Frame

0	N(S)	P/F	N(R)

- If w=7;
  - Each-I-Frame contains 2 three-bit fields for flow an error control.
    - N(S): Sequence number of the **sending** window
      - Like ACK
    - N(R): Sequence number of the **receiving** window
      - If las frame is error-free, N(R) contains next frame's number
      - If last frame has errors, N(R) contains number of faulty frame
- If w=127
  - Each I-Frame contains 2 sevent-bit fields for flow and error control.

HDLC Frame Structure - S-Frame

- S-Frame means that neither sides has data to send to the other.

1	0	Code	P/F	N(R)

Code	Abbreviation	Explanation
00	RR	Receive Ready
01	REJ	Reject - (go back n)
10	RNR	Receive Not Ready
11	SREJ	Selective Reject - (selective reject)

- **RR**:
  - It has four basic uses:
    - ACK
    - POLL
      - P=1
    - REJECT POLL
      - F=1
    - ACCEPT SELECT
      - F=1
- **RNR**:
  - It has three basic uses:
    - ACK
    - SELECT
      - P=1
      - If primary sends RR and P=1, it means POLL.
    - REJECT SELECT
      - F=1

- **REJ, SREJ**:
  - Used to return negative feedback from the receiver
    - REJ: Go Back N ARQ
      - It is used to inform the sender that the frame whose number is written in the N (R) field and the frames that come after it did not reach the receiver or that it received incorrectly, and to ensure that it is sent again.
    - SREJ: Selective Reject ARQ
      - It is used in the N (R) field to inform the sender that the data frame whose number is written on it not reach the receiver or that it was received incorrectly and to send it again.

HDLC Frame Structure - U-Frame

- Used to provide session control
- The data area is used to carry information required for system management functions

1	1	Code	P/F	Code

- 1^{st} code field consist of 2 bits
- 2^{nd} code field consist of 3 bits
- 2^5 = 32 different state
- These states (commands and answers) can be collected in 5 different categories:
  - Mode setting
  - Unnumbered exchange
  - Disconnection
  - Initialization
  - Miscellaneous
- **Mode setting:**
  - How will the transmission be?
    - 00-001 (SNRM-Set Normal Response Mode) -> w=7
    - 11-000 (SARM-Set Async. Response Mode) -> w=7
    - 11-100 (SABM-Set Async. Balanced Mode) -> w=7
- **Unnumbered Exchange:**
  - Data connection information exchange
    - 00-100 (UP-Unnumbered Poll): POLL request
    - 00-000 (UI-Unnumbered Info): exchange of date/time information to be used for sync.
      - UI would be a command or answer. If it is used for command, it transports list of parameters to be used for transmission. If it is used for answer, it carries information that determines the capability of the receiver.
    - 00-110 (UA-Unnumbered Ack): Sent in response to the UP command
- **Disconnection:**
  - There are 3 types of disconnection command.
    - 00-010 (DISC): **Sent by the first side** to terminate the connection to the other.
    - 00-010 (RD): It is used to notify the request to terminate the connection **from the second station** to the first.
    - 11-000 (DM): **when the address is sent** from the specified station to the station wishing to **establish the connection, it is sent as negative feedback** information to the **mode setting command**.

- **Initialization:**
  - Used for initializations for all sides.
    - 10-000 with P (SIM-Set Initialization Mode)
      - Command is sent from the first station to the second
      - UI command will be sent in response to SIM command
    - 10-000 with F (RIM-Request Initialization Mode)
      - It means that «I am waiting SIM command»
      - It is used when the second station cannot respond to the mode setting command without receiving the SIM command from the first.
- **Miscellaneous:**
  - 11-001 (RESET)
    - This is usually sent in response to a received FRMR code.
    - Explains that the secondary station must do the same.
  - 11-101 (XID)
    - Emphasizes that a **self-determining information is requested** from the secondary station.
    - Like questioning what your address is
  - 10-001 (FRMR)
    - Used to determine that a **syntax error** was encountered in the received frame.
- **P/F (POLL/FINAL)**
  - P/F bit is always 1

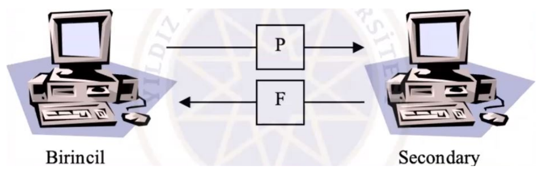

Figure 39: Poll/Final

Synchronous Protocols - Bit Oriented - HDLC Mechanism - Point to Point

- I, U and S frames
- 3-phase mechanism
  - One of the sides must install the link
    - in order to be able to exchange data sequentially
  - **User data, flow and control information** required for error control must be **transferred** between the two end.
  - One of the sides terminates the connection
  - (30.11.2020 Dersi dakika 15 izlemek lazım)

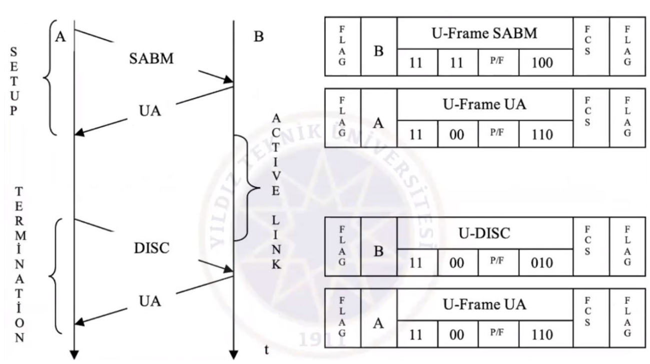

Figure 40: Connection Establishment

Synchronous Protocols - Bit Oriented - HDLC Mechanism - Multi Point

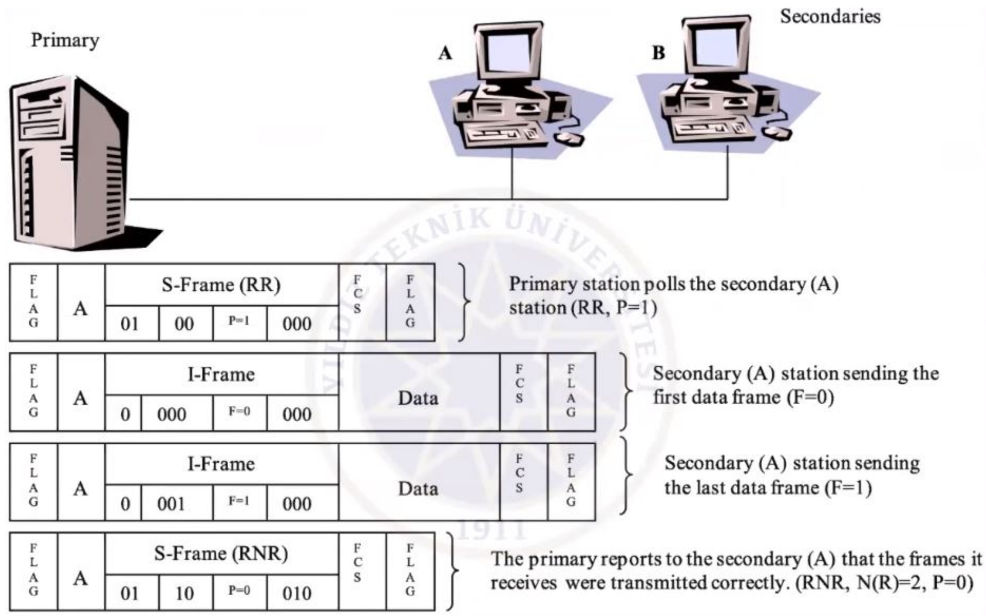

Figure 41: Multi Point Commincation Example

Synchronous Protocols - Bit Oriented - HDLC Mechanism - Combined

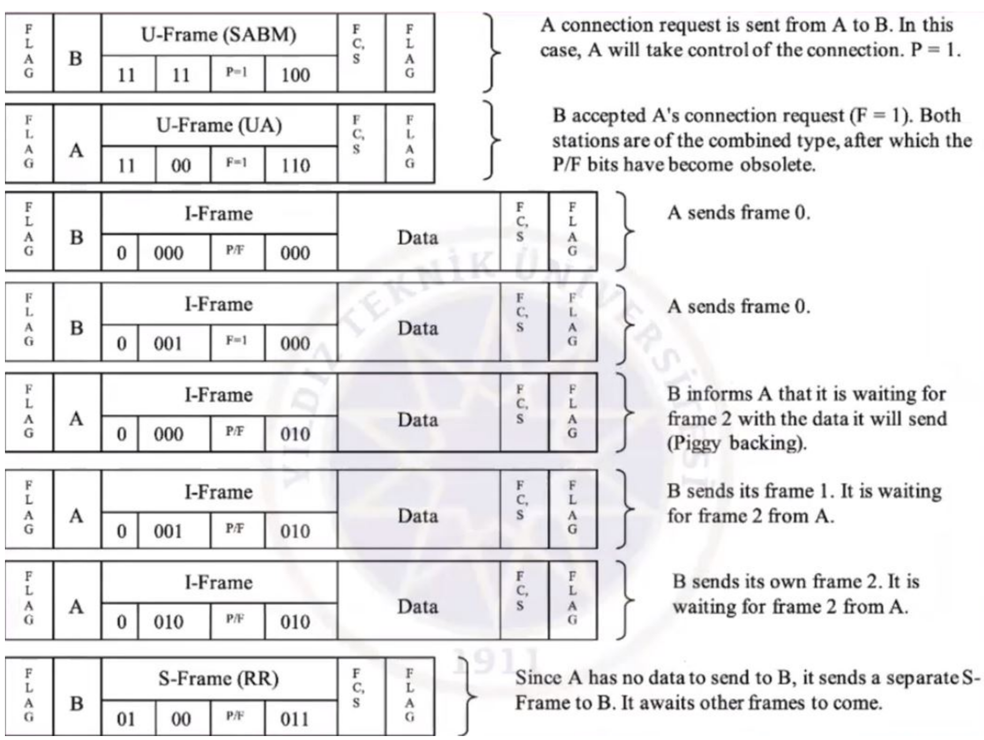

Figure 42: Combined Commincation Example

Local Area Networks (LAN)

- Multi-point mode
- Basic models:
  - Ethernet - IEEE 802
  - Token Bus - IEEE 802
  - Token Ring - IEEE 802
  - FDDI/CDDI (Fiber/Copper Distributed Data Interface) - ANSI
  - WLAN (Wireless LAN) - IEEE 802
- Data Link Layer is consist of HDLC
- 3 types of Media Access:
  - Fixed Based
    - TDMA, FDMA or CDMA (Time/Frequency/Code Division Multiple Access)
  - Contention Based
    - Aloha, CMSA
  - Token/Reservation Based
    - Token Ring

IEEE 802 Project

- LANs
  - 802.3 Ethernet
  - 802.4 Token Bus
  - 802.5 Token Ring
- Wireless LANs
  - 802.11 Wi-Fi
- Wireless PANs
  - 802.15 WPAN
  - 802.15.1 BlueTooth
  - 802.15.4 Zigbee
- WANs
  - 802.16 Wi-Max
- To ensure compatibility between protocols used in LANs
- MAC (Media Access Control)
- LLC (Logical Link Control)
  - Un-ack connectionless service
  - Connection mode service
  - Ack connectionless service

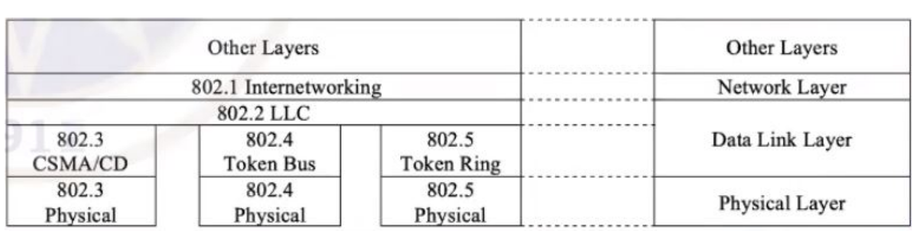

Figure 43: IEEE 802 vs OSI Layers

- Protocol Data Unit (PDU)
  - in LLC
  - DSAP (Destination Service Access Point)
  - SSAP (Source Service Access Point)
  - Control Field
  - Information Field

DSAP	SSAP	Control	Information

IEEE 802.3 Ethernet

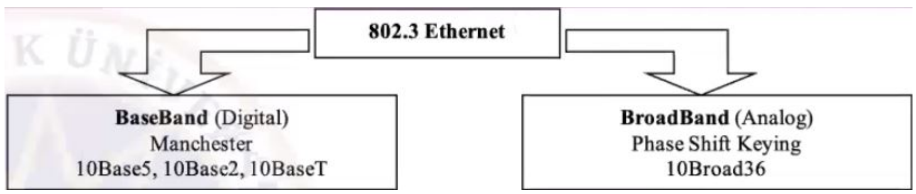

Figure 44: Ethernet

- 1972
- Xerox Corp.
- Aloha
  - Bob Metcalfe
  - 1973
  - Hawaii Islands
    - * Radio Network
  - Collision?
  - Utility Rate: 18%
- Slotted Aloha
  - Utility Rate: 37%

Carrier Sense Multiple Access (CSMA)

- The goal is to improve the Slotted Aloha
- Nonpersistent CSMA
- 1-Persistent CSMA
- p-Persistent CSMA
- CSMA/CD (Collision Detect)

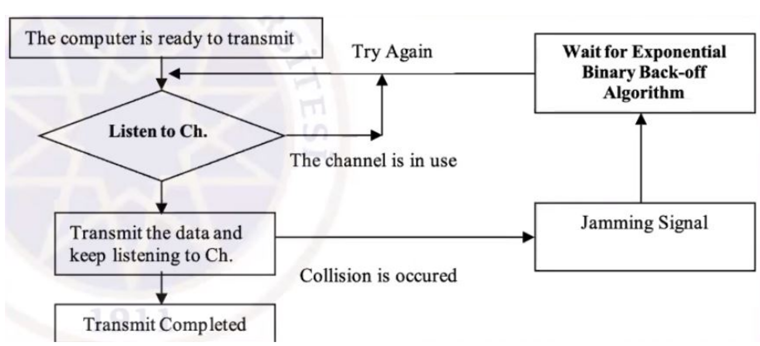

Figure 45: CSMA/CD

IEEE 802.3 Ethernet - Framing

7 byte	1 byte	2-6 byte	2-6 byte	2 byte	46-1500	4 byte
Preemble	SFD	Dest.Addr	Src.Addr.	Length	Data.Unit	CRC

- Preemble: **10101010**
  - for sync.
- SFD (Start of Frame Delimitter): **10101011**
- Shared and Switched Ethernet

IEEE 802.3 Ethernet Variations

- IEEE 802.3u - IEEE 802.3y - Fast Ethernet
  - 10 Mbps -> 100 Mbps
  - Auto Negotiation
- IEEE 802.3z - IEEE 802.3ab - Gigabit Ethernet
  - Cat5/5e/6/7/8
  - 100 Mbps -> 1000 Mbps
  - Auto Negotiation
- IEEE 802.3ae - IEEE 802.3ak - IEEE 802.3an - IEEE 802.3aq - 10 GigE
  - 1 Gbps -> 10 Gbps
- IEEE 802.3ba - 40/100G Ethernet
  - 40-100 Gbps

IEEE 802.4 - Token Bus

- In worst case scenarios, some computers seem to wait too long to transmit
  - General Motors
  - 1980s
- Bus and Tree Topology
- Each computer recognizes the computers on its right and left
- After the logical ring is established, the computer with the highest number will transmit
- Gives the control frame (Token) to its neighbor
- Collision is impossible
- New computers can be added or removed
- IEEE 802.4 MAC protocol is quite complex
  - Each computer included in the system must keep to 10 different time information and
  - Evaluate approximately 24 status information.
- 75 Ω Coaxial Cable
- 3 Different Modulation Techniques are used
  - Phase continious frequency shift keying
  - Phase coherent frequency shift keying
  - Multilevel duobinary amplitude modulated shift keying
- Max speeds: 1,5 ve 10 Mbps

,

IEEE 802.4 - Token Bus - Framing

- SD : Starting Delimitter
- FC : Frame Control
- ED : Ending Delimitter

1 byte	1 byte	1 byte	2-6 byte	2-6 byte	0-8182	4 byte	1 byte
Preemble	SD	FC	Dest.Addr	Src.Addr.	Data.Unit	CRC	ED

- Frame size is almost 5 times bigger than 802.3
- Priority mechanism
  - 4 levels priority: 0, 2, 4, 6

IEEE 802.5 - Token Ring

- It uses a technique based on the principle that the computers to be transmitted send their data sequentially.
- Token size: 3 bytes (even if the line is empty)
- Token Re-Sizing

- Example: Transmission speed: R Mbps
- Bit extraction rate: 1/R μsec
- Signal propagation rate: SP m/μsec
- Every bit occupies on ring: SP/R m
- What is the number of bits (b) that can be simultaneously on an L-meter ring?
- b = L * R / SP

- **Example:** SP: 200m/μsec
- R: 1/R μsec
- L: 1000m
- b:?
- b = L * R / SP
- b = 1000 * 1 / 200 = 5-bit

IEEE 802.5 - Token Ring - Priority and Reservation

- For reservation: AC (Access Control) is used.
- Time Limitation
- Monitor Station
  - No Token Frame
  - Orphan Frame

IEEE 802.5 - Token Ring - Framing

- NIC (Network Interface Card) Addresses (6-byte)
- Differential Manchester Coding
- Max speed are 4 and 16 Mbps (**IEEE 802.5t: 100 Mbps, IEEE 802.5v: 1 Gbps**)
- First sending bit is MSB (differential from 802.3 and 802.4)

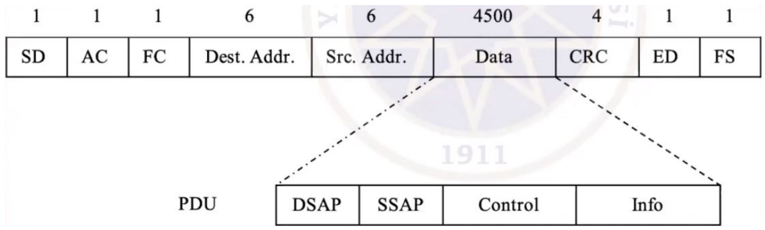

Figure 46: Token Ring - Framing Structure

SD	AC	ED

Table 8: Token

SD	ED

Table 9: Abort

Fiber Distributed Data Interface (FDDI)

- ANSI and ITU-U standart
- Fiber optics: 100 Mbps
- Token
- S-Frame (Synchronous Frame) - priority
- A-Frame (Asynchronous Frame)
- Timing Register
  - SA (Synch. Allocation)
  - TTRT (Target Token Rotation Time)
  - AMT (Absolute Maximum Time)
  - TRT (Token Rotation Timer)
  - THT (Token Holding Time)
- 4B/5B Coding
  - Using NRZ-I

4 Bit	**Explanation**
00000	Q (Quit)
11111	I (Idle)
00100	H (Halt)
11000	J (Used as a starting marker)
10001	K (Used as a starting marker)
01101	T (Used as a starting marker)
11001	S (Set)
00111	R (Reset)

4 Bit	**5 Bit**	**4 Bit**	**5 Bit**
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

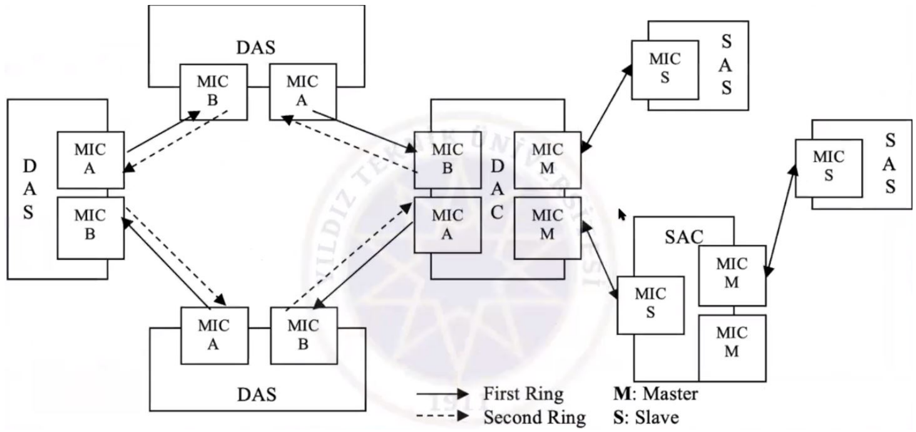

Figure 47: FDDI Mechanism

IEEE 802.11 - WiFi

- RF
- Infrared
- Static
- Mobile, Nomadic
  - Roaming
- Carrier
- Non-Line-of-Sight Propagation (NLSP)
- Continuation of the Ethernet
- CSMA/CD -> CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance)
  - Antenna type: half-duplex
  - Fading
    - The signal decreases inversely with the square of the distance
  - Noise
  - Detecting collisions is almost impossible
- IEEE 802.11 MAC
  - DCF (Distributed Coordination Function)
    - CMSA/CA
  - PCF (Point Coordination Function)
    - Polling

IEEE 802.11 - WiFi - DCF (Distributed Coordination Function)

- DCF basic access method
  - Checks if the line is empty
  - If it sees that the line is empty for DIFS (DCF Inter-Frame Space) time, it switches to transmission.
    - Waits until DIFS (back-off) times is up
  - The back-off timer starts to decrease (DIFS)
  - It transmits when the back-off time value is 0.
  - Timing slots
  - Receiving node sends acknowledgment (ACK) after waiting the time specified by SIFS (Short Inter Frame Space).
    - SIFS < DIFS
  - In case a collision;
    - EIFS (Extended Inter Frame Space)

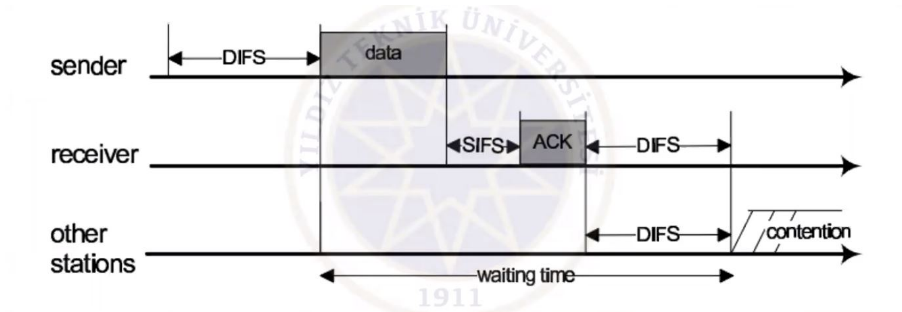

Figure 48: DCF Structure

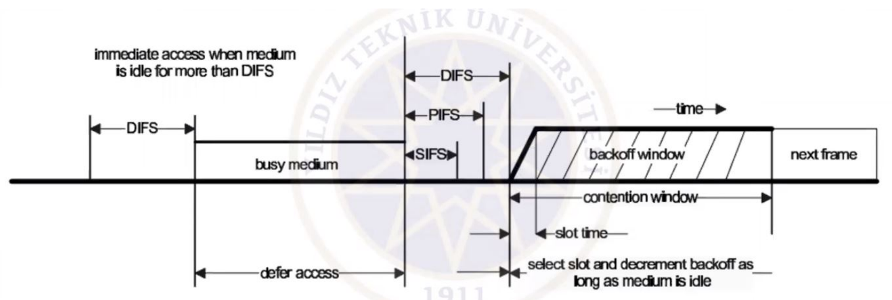

Figure 49: DCF Structure 2